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## DEVELOPMENT, IMPLEMENTATION AND EVALUATION OF SATELLITE-AIDED AGRICULTURAL MONITORING SYSTEMS

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| 16. Abstract<br><br>This document is a semi-annual progress report for ERIM research activities in support of AgRISTARS Inventory Technology Development Project in the use of aerospace remote sensing for agricultural inventory.<br><br>Three task areas are described:<br><br>1) Corn and Soybean Crop Spectral/Temporal Signature Characterization<br>2) Efficient Area Estimation Techniques Development<br>3) Advanced Satellite and Sensor System Definition<br><br>Studies include a statistical evaluation of the impact of cultural and environmental factors on crop spectral profiles, the development and evaluation of an automatic crop area estimation procedure, and the joint use of SEASAT-SAR and Landsat MSS for crop inventory.<br><br><i>Original photography may be purchased<br/>from ERIS Data Center<br/>Sioux Falls, SD 57198</i> |  |  |           |
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SEMI-ANNUAL REPORT

DEVELOPMENT, IMPLEMENTATION AND EVALUATION OF  
SATELLITE-AIDED AGRICULTURAL MONITORING SYSTEMS

by

R. Cicone, E. Crist, M. Metzler, D. Nuesch

This report describes results of research performed  
in support of the Inventory Technology Development  
Project of the AgRISTARS Program.

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June 1982



## PREFACE

The Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing program, AgRISTARS, is a program of research, development, evaluation and application of aerospace remote sensing for agricultural resources. This program is a cooperative effort of the National Aeronautics and Space Administration (NASA), the U.S. Departments of Agriculture, Commerce, and the Interior and the U.S. Agency for International Development. AgRISTARS consists of eight individual projects.

The research reported herein is sponsored by the Inventory Technology Development (ITD) Project under the auspices of the Earth Resources Applications Division of NASA at the Johnson Space Center. Dr. Jon Erickson is the NASA Manager of the ITD Project and Mr. Lewis Wade is the Technical Coordinator of the reported effort.

Research herein reported in the use of remote sensing for inventory and assessment of agricultural commodities is performed under NASA Contract NAS9-16538 by the Environmental Research Institute of Michigan's Infrared and Optics Division headed by Marvin R. Holter, Executive Vice-President of ERIM, under the technical direction of Robert Horvath, Program Manager and Richard Cicone, Task Leader.

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## 1.0 INTRODUCTION

This semi-annual report describes progress made by the Environmental Research Institute of Michigan (ERIM) in support of the Inventory Technology Development (ITD) Project of AgRISTARS during the period 1 November 1981 to 30 April 1982.

The major objective of ITD is to investigate methods for "using space remote sensing technology to provide objective, timely and reliable forecasts of foreign crop production without requiring ground observations" [1]. ERIM's primary focus is on research of technical issues requiring attention in order for ITD to achieve its principle objective.

### 1.1 TASKS AND OBJECTIVES

The research effort is organized into three tasks:

- 1) Corn and Soybean Crop Spectral/Temporal Signature Characterization
- 2) Efficient Area Estimation Techniques Development
- 3) Advanced Satellite and Sensor System Definition

The first two tasks emphasize use of Landsat Multispectral Scanner, while Task 3 explores other alternatives.

Task 1 aims at providing the underlying understanding of the spectral and temporal behavior of key crops that would enable crop assessment and identification without the use of ground observations. The near term objectives of this task include:

- Determine the seasonal and regional variability in the spectral development patterns of corn, soybeans, and confusion crops (e.g., sorghum)
- Determine the environmental and cultural factors responsible for that variability

- Evaluate alternative Landsat features in light of their sensitivity to or robustness against these factors.

In the long term this task would provide basic research in support of methods that would adapt automatic information extraction techniques to local or regional conditions without direct ground observation.

Task 2 explores the potential of automatic information extraction by exploiting that understanding gained in crop signature characterization in an area estimation methodology. Two key objectives in this research are to:

- Explore factors influencing and methods for automatic extraction of crop area (with emphasis on corn and soybeans) from Landsat, without the use of ground based training data, that adapts to locally specific conditions.
- Examine alternative techniques for estimating proportions in the presence of mixed pixels.

In the long term this task would explore factors influencing and methods for automatic extraction of crop area that adapt to regionally specific conditions.

Task 3 is designed to examine the potential of remote sensing alternatives to the Landsat Multispectral Scanner for crop assessment and inventory. The primary near term objective of this task is to:

- Research crop related information extraction techniques for engineered alternative sensor configurations other than Landsat MSS alone, including the Thematic Mapper, Meteorological Satellites (NOAA-6 and NOAA-7 AVHRR and NIMBUS7 CZCS) and Radar Systems (SEASAT-SAR).

In the long term this task would point at developing an objective technique for future sensor system definition.

## 1.2 REPORTING PERIOD PROGRESS

Substantial progress has been made toward achieving the objectives of the three tasks previously identified.

Efforts in Task 1, Crop Signature Characterization, have emphasized conducting statistical analyses of corn and soybean field measurement data collected by the Laboratory for Applications of Remote Sensing (LARS) for the Supporting Research Project of AgRISTARS [2]. Table 1 identifies key accomplishments. Section 2 provides a technical discussion of highlights of the research.

The development and evaluation of an automatic corn and soybean area estimation procedure was the principle emphasis of Task 2, Efficient Area Estimation Techniques Development. Table 2 identifies key accomplishments, while Section 3 discusses the technical effort.

The key achievement in Task 3, Satellite and Sensor System Definition, was an analysis of the joint use of SEASAT SAR and Landsat MSS for agricultural inventory. This study examined the potential of a cellular automata inspired approach for the extraction of information from the radar data, and identifies two key features, called tone and texture, that were found to relate uniquely to crop cover. The key accomplishments during this reporting period are presented in Table 3. Section 4 presents a discussion of the SAR/MSS analysis.

Appendix A lists reports and articles that relate to the efforts of this reporting period.

TABLE 1. CHARACTERIZATION OF CROP SIGNATURES  
Progress to Date

- Field Measurement Data Analysis

- + Environmental and cultural factors affecting corn and soybean spectral development patterns were analyzed
  - ++ Typical corn and soybean spectral development patterns were formulated, corn exhibiting a greenness plateau not seen in soybean or grains
  - ++ Key factors analyzed included nitrogen fertilization, planting date, population, varietal, row spacing and soil moisture effects
  - ++ The effect of each factor on the typical trajectory was statistically quantified
- + The relationship of corn and soybean profile features to crop development stages was established
  - ++ Unexpectedly, corn achieved peak greenness prior to peak LAI, a result explainable by the canopy structure
  - ++ Soybean vegetative and reproductive stages were not correlated to profile features, probably due to the indeterminate nature of the plant; unlike corn canopy, closure was found to be the overriding factor
- + Detailed analysis of derived profile features was undertaken
  - ++ Profile features are not dependent on date of acquisition
  - ++ 100% discrimination of corn and soybeans was achieved asking a peak greenness and a plateau feature

- Landsat Data Analysis

- + Initiated an analysis of alternative Landsat coordinate systems and green measure indicators
- + Digitized ground truth for 16 1980-81 sites in the Argentina Indicator Region was incorporated into the RT&E data base at JSC



TABLE 2. EFFICIENT AREA ESTIMATION TECHNIQUES DEVELOPMENT  
Progress to Date

- Developed Automatic Corn and Soybean Classification Technique Based on 'Classic' Crop Features that are Adapted to Segment Specific Factors (e.g., acquisition history)
  - + Technology, based on hierarchical decision logic, was configured into C/S-1B on LARS 4341 and EODL AS/3000
  - + Conducted developmental, shakedown and independent testing
    - ++ Accurate estimates (within 11%) of corn, soybean and total summer crop were achieved
    - ++ Estimates demonstrated low (3 to 9% std. dev.) variance, comparable to analyst based systems
    - ++ High processibility achieved (greater than 60%)
    - ++ Principle error sources include mixed targets and confusion between 'corn' and 'other' classes
- Automated Subcomponent is Under Development that would Minimize Errors Due to Boundary Pixels
  - + Technique is based on mixture decomposition technology
    - ++ Only pure pixels are labeled
    - ++ Mixed pixels are assigned mixed labels by spectrally decomposing the pixels into pure component classes and labeling neighboring representatives of these classes
    - ++ The technique is expected to be less sensitive to error induced by direct labeling of the mixed target or methods involving replacement, or elimination of the sample
  - + Technique is being configured into C/S-1C to be implemented on EODL AS/3000

TABLE 3. SATELLITE AND SENSOR SYSTEM DEFINITION  
Progress to Date

- Currently Engineered Sensor Systems

- + Exploration of the combined use of visible range sensor (MSS) and a microwave sensor (SEASAT-SAR) for digital crop inventory was undertaken
  - ++ A cellular automata approach was used to remove coherent speckle from the SAR
  - ++ Crop related radar features called tone and texture were found to relate to crop canopy structural features
  - ++ Use of canopy structural features combined with MSS could permit discrimination six weeks prior to what is possible with Landsat alone
- + Prepared a reference summary of available civilian spaceborne observation systems including NOAA, GOES, Nimbus, and Landsat
- + In process of building field measurement data base for simulation analysis of TM and METSAT including: LARS Field Measurement data, ERIM's ERIS data base and Imperial Valley data base

- Future Satellite and Sensor System Design

- + A simulation methodology is under investigation as a mechanism to objectively determine key system parameters required to meet pre-specified crop inventory information requirements
  - ++ Effort is initiated as ERIM Internal Research and Development and will be a foundation for future ITD efforts
  - ++ Suits canopy reflectance model combined with sensor signal simulation capability form the basis of the approach
  - ++ Approach is based on parameter sensitivity analysis

## 2.0

### CORN AND SOYBEAN CROP SIGNATURE CHARACTERIZATION

In order to successfully inventory or assess the condition of agricultural crops from space, we must have techniques which are based on a solid understanding of the plants themselves, of the dynamics of the plants' interactions with their environment, and of the expression of those interactions in the spectral signal received by the sensor. The automated crop identification techniques required by efficiency constraints on any large scale system must take into account both the normal or average spectral characteristics of key target classes, and the likely changes in those characteristics resulting from changes in field conditions, if they are to provide accurate data over many years and broad geographic regions. Crop condition assessment techniques must account for the interactions between spectral and developmental events, and the expression of stresses or other influencing factors on crop spectral patterns. It is the goal of the activity reported here to develop that physically based understanding of what remotely sensed data can tell us about the identity and vigor of targeted agricultural commodities.

The Tasseled Cap Transformation of Landsat MSS spectral bands developed by ERIM personnel [3] provides both a reduction in data volume and an improvement in the physical interpretability of data values. The resulting Greenness and Brightness variables are well correlated to the amount of green vegetation and the brightness of the soil or target albedo respectively, and thus facilitate evaluation of spectral observations as well as understanding of the spectral expression of field events. ERIM's development of techniques for describing and analyzing the continuous patterns of crop spectral development (termed "profiles") [4,5] provides a framework within which crop spectral behavior may be evaluated. Since important spectral or developmental events are not restricted to the particular times of data collection, derivation of profiles based on the set of available data values allows a more complete

description and analysis of crop spectral development. Careful, physically-sound interpolation can greatly enhance our ability to extract meaningful information on intermittent data.

The research reported here was undertaken to determine: a) the average or normal profiles for corn and soybeans, b) the effects of certain changes in field conditions or cropping practices on those profiles, c) the association between features of those profiles and crop development stages, and d) the separability of corn and soybeans based on profile features.

Included in this reporting are two areas of research largely carried out in FY81: 1) review of the literature of agronomic research to understand the development of corn and soybean plants, and their responses to stress, variations in cropping practices, etc., and 2) evaluation of the changes in Green Reflectance profiles brought about by cultural or environmental factors. With the inclusion of these results, this report provides a complete summary of the research results as outlined above.

The data used in these analyses were ground-level reflectances, collected by and at Purdue/LARS for NASA [2]. Originally recorded as Landsat MSS inband reflectances, they were converted to Tasseled Cap equivalent coordinates, labeled Green Reflectance and Bright Reflectance. Associated with these spectral observations were data related to plant and canopy conditions and characteristics. A total of 147 corn plots and 171 soybean plots from three growing seasons were available for analysis.

A profile analysis technique developed at ERIM in FY81 was used to: 1) derive smooth, continuous curves from the intermittent data points and 2) extract profile features for comparison and evaluation [5]. The features, as illustrated in Figure 1, relate to the maximum profile value and the time intervals between points on the profile.

Average Profiles. Figures 2 and 3 show the average or normal profiles in both Green Reflectance and Bright Reflectance for corn and

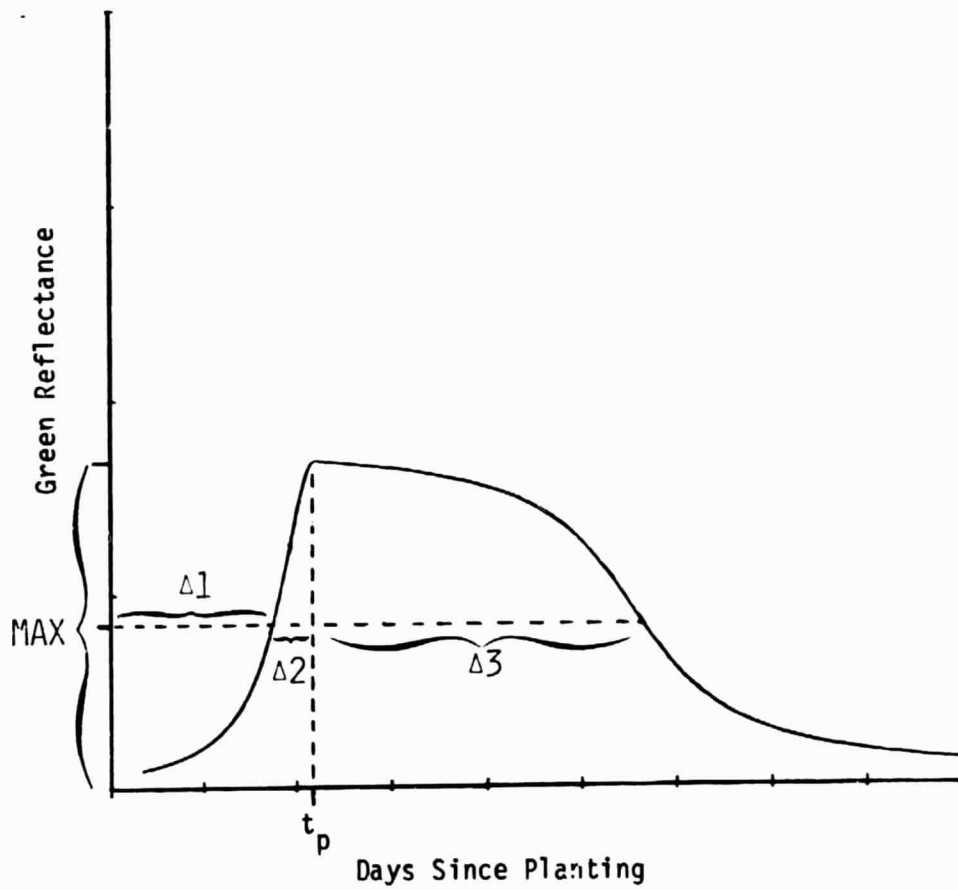


FIGURE 1. FEATURES USED IN PROFILE ANALYSIS

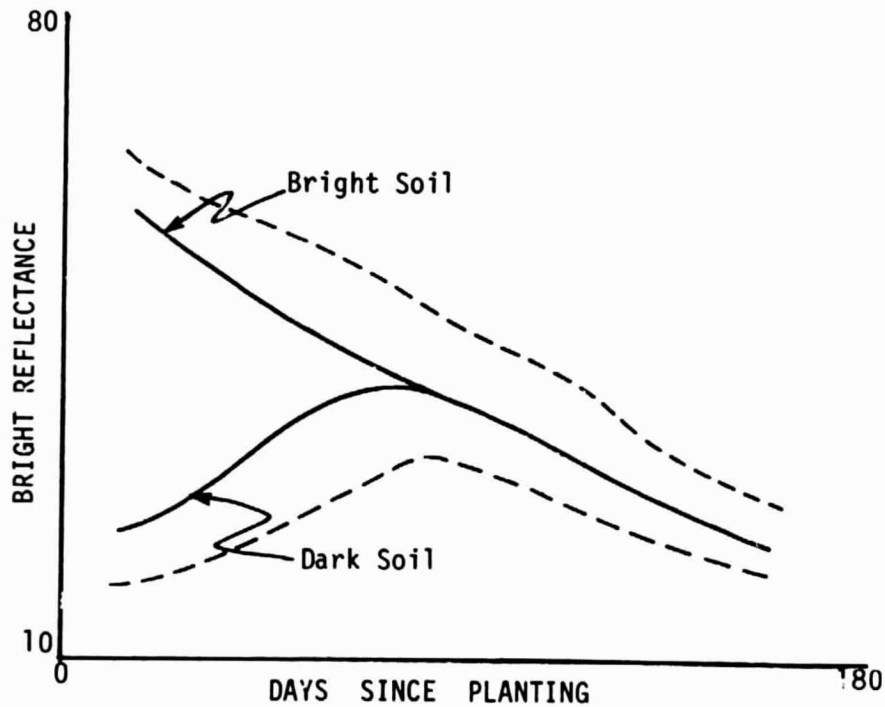
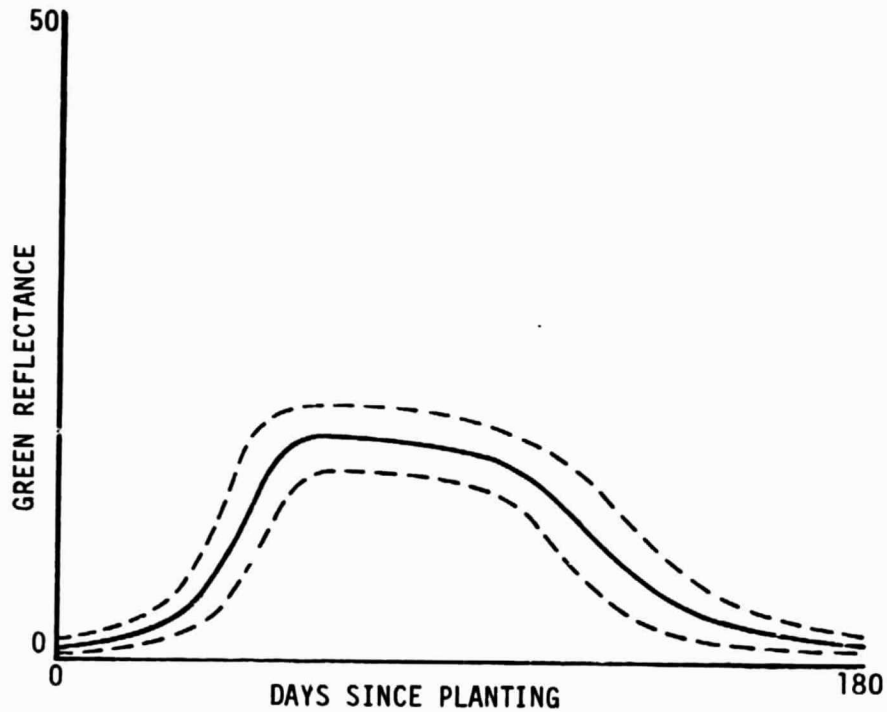


FIGURE 2. AVERAGE CORN PROFILES

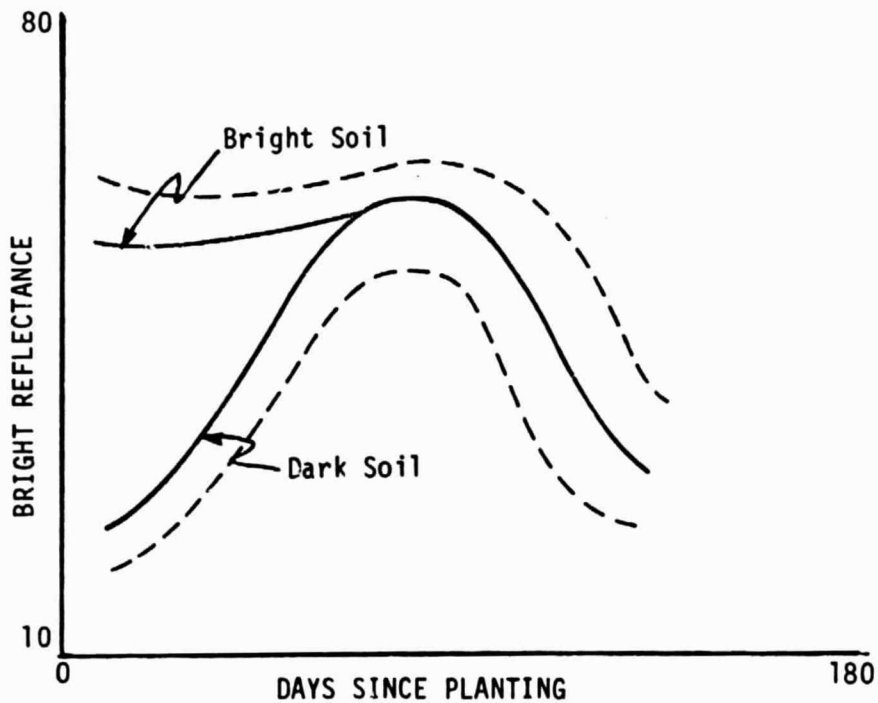
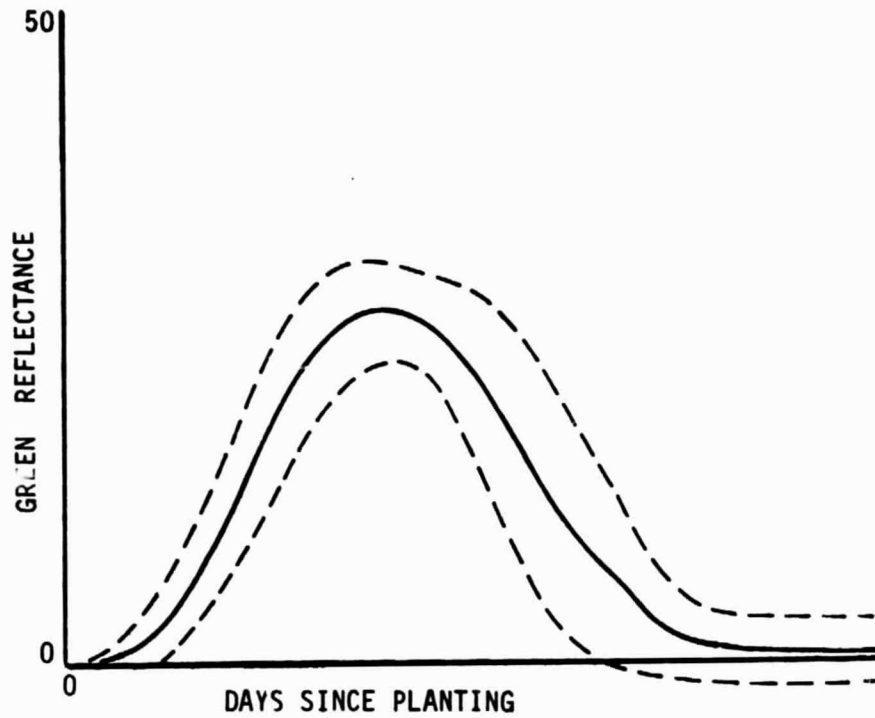


FIGURE 3. AVERAGE SOYBEAN PROFILES

soybeans. These profiles are averages of those corn or soybean plots that were free from anomolous data values and had observations throughout the growing season. The Green Reflectance profiles are actual mathematical averages, with one standard deviation denoted with the dashed lines. Because of the effects of soil variability on Bright Reflectance profiles in the early season, mathematical averaging was not feasible, so average Bright Reflectance profiles were derived based on qualitative analysis.

Of particular interest in the profiles illustrated is the "plateau" or flattened top of the corn Green Reflectance profile. This feature was seen in most of the corn plots, and additional evidence for its existence was also found [5]. As a result, a mathematical profile model for corn Green Reflectance which explicitly includes the plateau was developed at ERIM. The model is of the form:

$$G(t) = \begin{cases} \frac{A}{1 + Q^2(t-t_p)^2} ; & t \leq t_p \\ \frac{(A-25)*g(\alpha,\Delta)}{\pi} (\cot^{-1}[\alpha(t-t_p - \Delta)]) + 25 ; & t > t_p \end{cases} \quad (1)$$

where

$G(t)$  = Greenness at time  $t$

$A, t_p, Q, \alpha, \Delta$  = model parameters

$A$  = maximum function value (peak Greenness)

$t_p$  = day of maximum function value

$Q$  = inverse time from first half-peak to peak

$\alpha$  = controlling factor for shape after peak (flatness of peak, steepness of decline)

$\Delta$  = time of peak to second half-peak

and



$$g(\alpha, \Delta) \equiv \pi / \cot^{-1}(-\alpha * \Delta)$$

(provides continuity at  $t = t_p$ )

The average Corn Greenness profile shown in Figure 2 is based on profiles obtained through application of this model. The soybean profiles were derived with a cubic smoothing spline.

Cultural and Environmental Effects. The impact of nitrogen availability, planting date, row spacing, plant population and variety were assessed in terms of changes in profile features. Many of the experimental treatments had significant effects on profile features, and particularly on the peak value of the Green Reflectance profiles. Figure 4 is provided as an example of the results obtained. Late planting of corn, which generally exposes the plants to higher temperatures throughout much if not all of their development cycle, tends to result in more rapid emergence and growth, while the cool temperatures encountered with early planting tend to delay emergence and retard growth. Both situations tend to be more stressful than a "normal" planting date. The figures illustrate the effects of planting date on profile characteristics.

An additional important piece of information is that many of the experimental treatments affect the same profile features. For example, the maximum Green Reflectance value may be reduced as a result of early or late planting, reduced nitrogen availability, wider rows, or lower population densities. Thus in terms of crop condition assessment, it appears that use of spectral data alone for determination of the presence or absence of a specific stress or condition is probably not feasible, though a general assessment of crop condition might be possible.

Association of Spectral and Development Events. Development stage data, smoothed and interpolated in a manner similar to that used for the spectral data, was used to determine the stages of development associated with key Green Reflectance profile features (Figure 5 provides an example of the merging of the two data types).

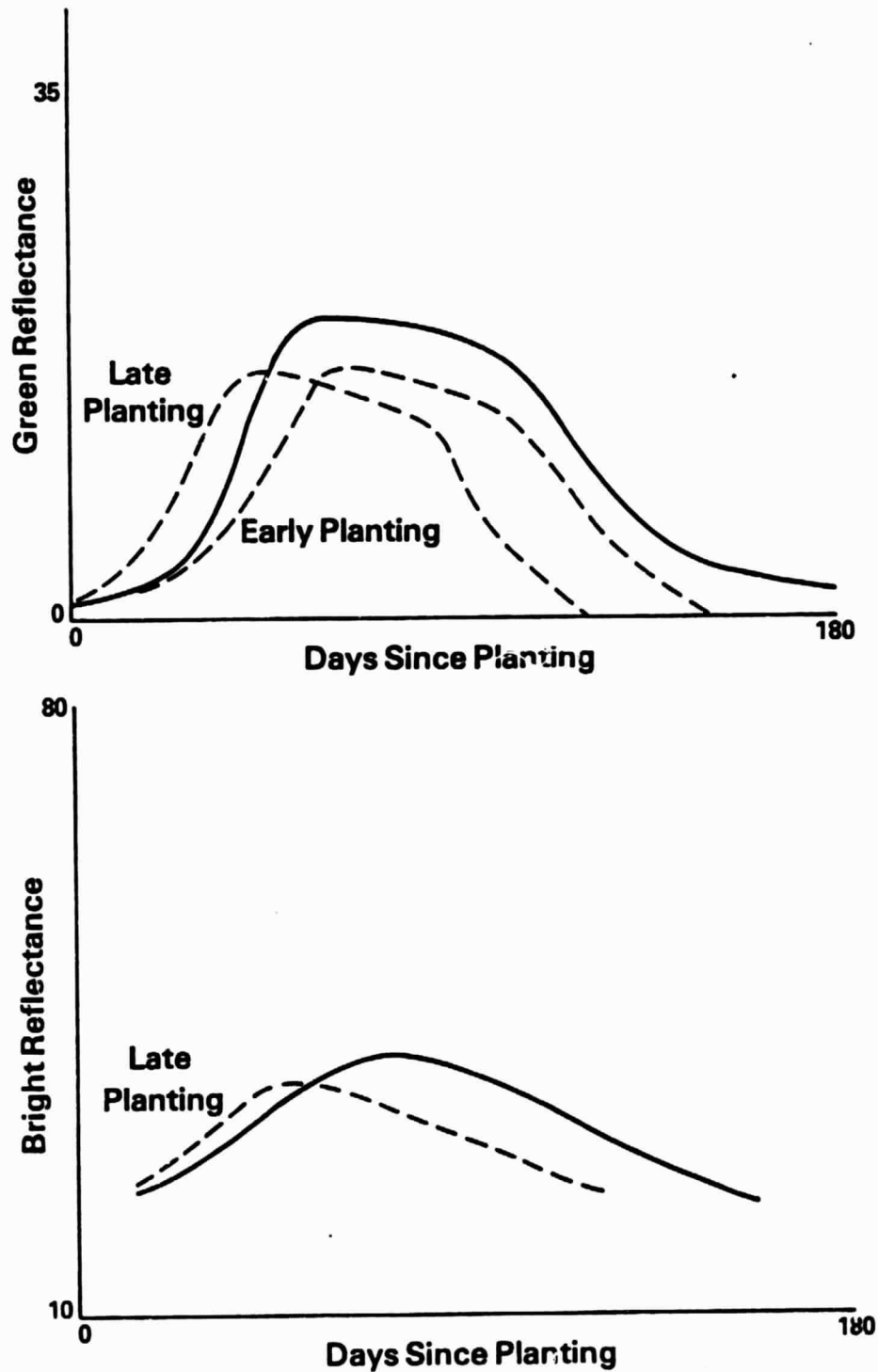


FIGURE 4. EFFECTS OF PLANTING DATE ON CORN PROFILES

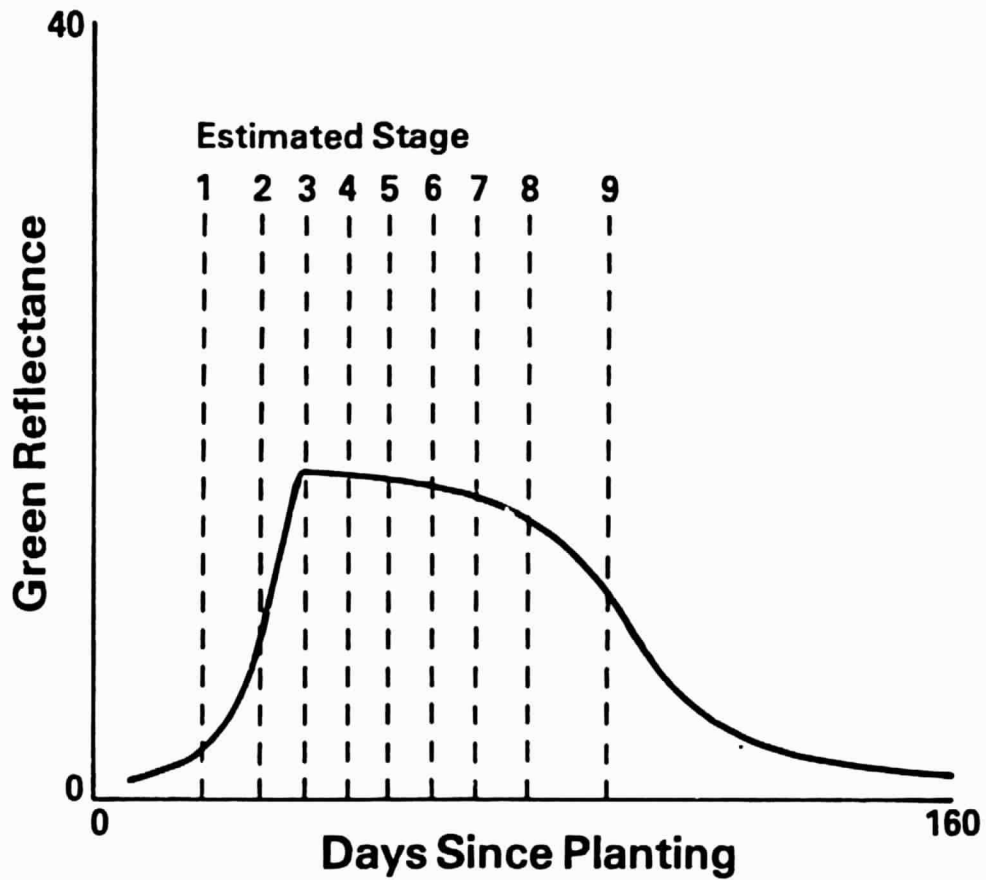


FIGURE 5. SAMPLE RESULT - PROFILE/HANWAY STAGE ASSOCIATION

For corn, peak Green Reflectance occurred at Hanway stage 2.5 to 3.0, well before tasseling or silking (the stage at which peak LAI usually occurs) and also before apparent maximum canopy closure. The lack of increase in Green Reflectance after stage 2.5 to 3.0 is probably the result of changes in canopy geometry, particularly the spreading of green leaf area over a greater vertical depth, an increase in the proportion of canopy components comprised of stems, perhaps an increase in the vertical orientation of the leaves, and after stage 4.0, the introduction of tassels into the top layer of the canopy. The plateau of corn Green Reflectance ends in response to the increased emphasis on dry matter accumulation in the kernels.

Soybeans were found to have little association between a particular stage of development and a particular profile feature. When no lodging was reported the peak Green Reflectance value tended to occur at the maximum vegetative stage, but where lodging was reported, the peak often occurred much earlier. Since many soybean varieties are indeterminate, there is no "final" vegetative stage for all plants, nor is there any simple association between vegetative and reproductive stages of development. Thus neither vegetative nor reproductive stages could be connected to the peak in the soybean profile. A much stronger association was found between soybean peak Green Reflectance and maximum percent cover or Leaf Area Index.

Separability of Corn and Soybeans. Features of corn and soybeans profiles were compared to determine the major sources of separability. Both the previously mentioned crop profile model and the more general spline technique, which made no assumption concerning the plateau feature, were used for corn, the latter because it gave a better idea of the results one might achieve in a more operational setting.

The primary sources of separability in Green Reflectance were the peak profile value (higher for soybeans) and the rate of Green Reflectance decline after the peak (faster for soybeans). Indeed, in this data set these two features together provided 100% separability (Figure

6) using the more general spline technique. It should be noted that the rate of decline difference was probably largely related to the plateau feature of corn. Very little early season separability was apparent, either in terms of rates of green-up or relative slopes of the ascending portion of the average Green Reflectance profiles, though mid-season separation based on peak Greenness was possible.

The key source of separability in Bright Reflectance was, again, the peak value (soybeans higher). Figures 7 and 8, composites of the average profiles shown in Figures 2 and 3, show that the differences in peak Green Reflectance and Bright Reflectance are correlated, and together express the tendency of soybeans to move farther up the "green arm" than corn. This feature is used in current corn/soybean labeling techniques [6].

The interaction of field conditions with the features providing greatest separability are such that one should expect, in particular circumstances, to see degradation in discrimination results. For example, highly fertilized or densely-planted corn might achieve peak profile values similar to those of soybeans, particularly if those soybeans are planted early or late or in wide rows. Other such combinations can also be hypothesized.

Conclusions. These studies have clearly shown that the characteristic patterns of corn and soybean spectral development can be significantly altered by fairly common variations in field conditions or cropping practices. Further, while the two crops can be well distinguished in the profile feature space, changes in conditions can adversely affect their separability. However, using the knowledge gained here to develop procedures which can adapt their expectations of crop spectral characteristics to reported local conditions should enhance our ability to accurately detect and distinguish between crops, even in the presence of atypical conditions.

For crop condition assessment, these studies show that the chances of detecting stress conditions using spectral data alone are not great.

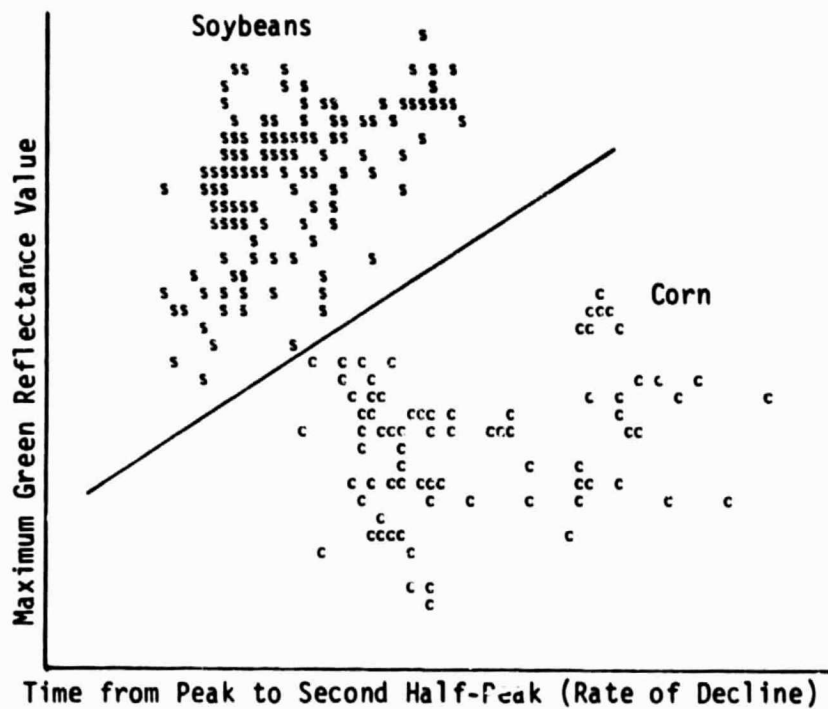


FIGURE 6. SEPARABILITY OF CORN AND SOYBEANS BASED ON  
DERIVED PROFILE FEATURES

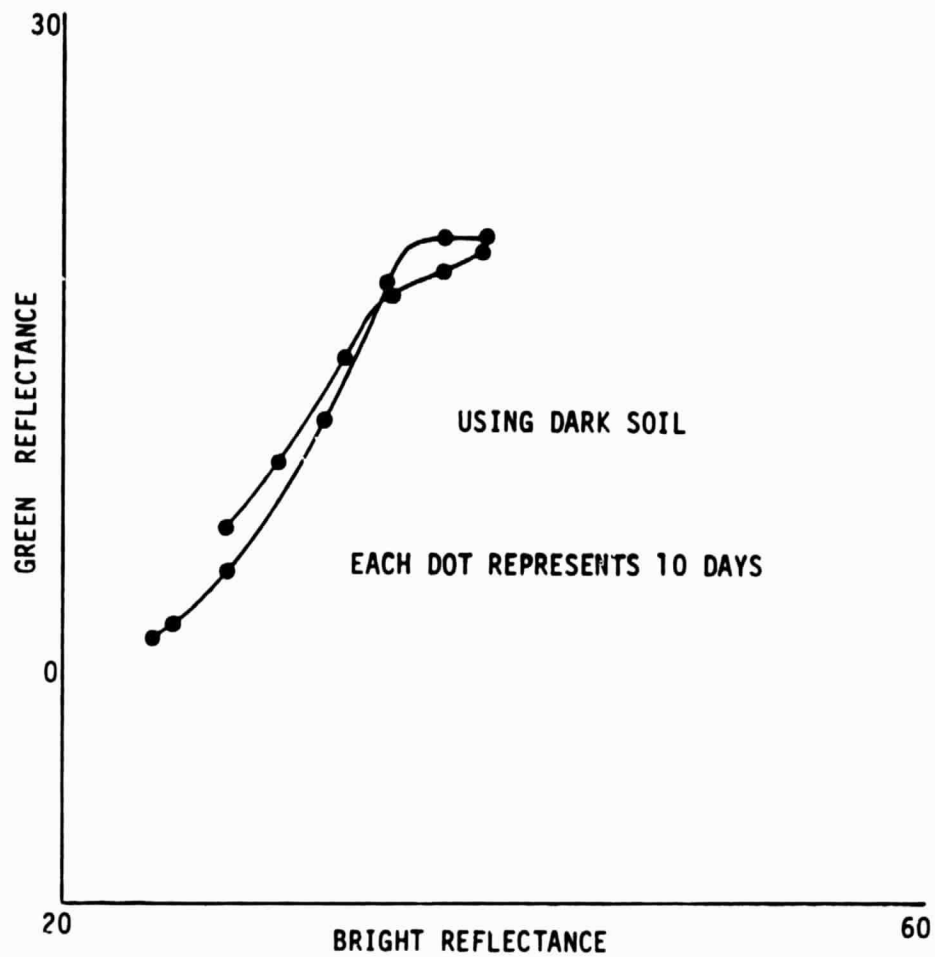


FIGURE 7. AVERAGE CORN GREEN REFLECTANCE/BRIGHT REFLECTANCE  
TRAJECTORY

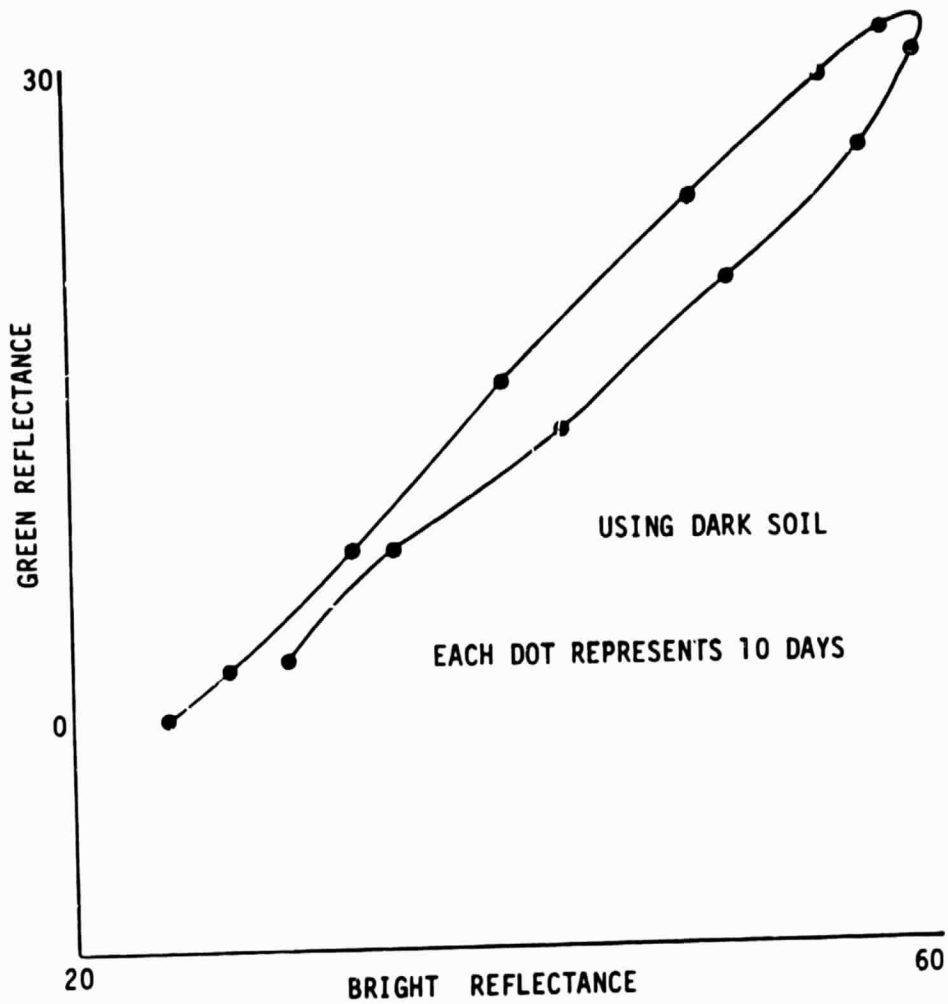


FIGURE 8. AVERAGE SOYBEAN GREEN REFLECTANCE/BRIGHT REFLECTANCE TRAJECTORY



Spectral data might, however, provide a means of corroborating expectation of stress conditions determined in some other manner, since the effects of those conditions on profile characteristics can now be predicted. The observed association of corn stages of development with profile features, especially the Green Reflectance peak, may provide at least one anchor point for estimating the times of occurrence of development stages critical with regard to crop condition or production. The lack of any such association in soybeans, on the other hand, offers little hope for a similar anchor point with this crop.



## 3.0

## EFFICIENT AREA ESTIMATION TECHNIQUES DEVELOPMENT

The performance of a crop inventory for a large area in a timely fashion requires an area estimation procedure which is efficient and accurate over the range of crop conditions found in the area of interest, without relying on ground-based observations. Traditionally, there has been a tradeoff between efficiency and accuracy, with automation providing the efficiency at the expense of flexibility, and analysts providing the adaptability needed for the required level of accuracy. Attempts at developing automated crop identification techniques which could approach the adaptability of a human analyst have relied on ground-based observations to train the technique to each particular set of conditions.

A thorough understanding of the crops themselves, as well as the processes involved in transforming radiation incident upon the crops into signals from the sensor is required for the development of a technique which does not require ground based data for training. Previous work at ERIM, the University of California at Berkeley, and elsewhere has led to a sound understanding of these phenomena, and a crop identification methodology employing the spectral developmental profiles of the crops of interest has evolved from that understanding [7,8,9,10]. These profiles describe the development of the crop over time in terms of Tasseled Cap Greenness, a feature derived from Landsat data space which is well correlated to the amount of green vegetation in the target [3].

The research reported here led to the development of an automatic corn and soybean labeling technique which attempts to adapt itself to scene-specific conditions. The procedure may be thought of as two interrelated parts: 1) selection of and identification of targets with "classic" profiles and 2) classification of remaining targets, which have "non-classic" profiles (see Figure 9).

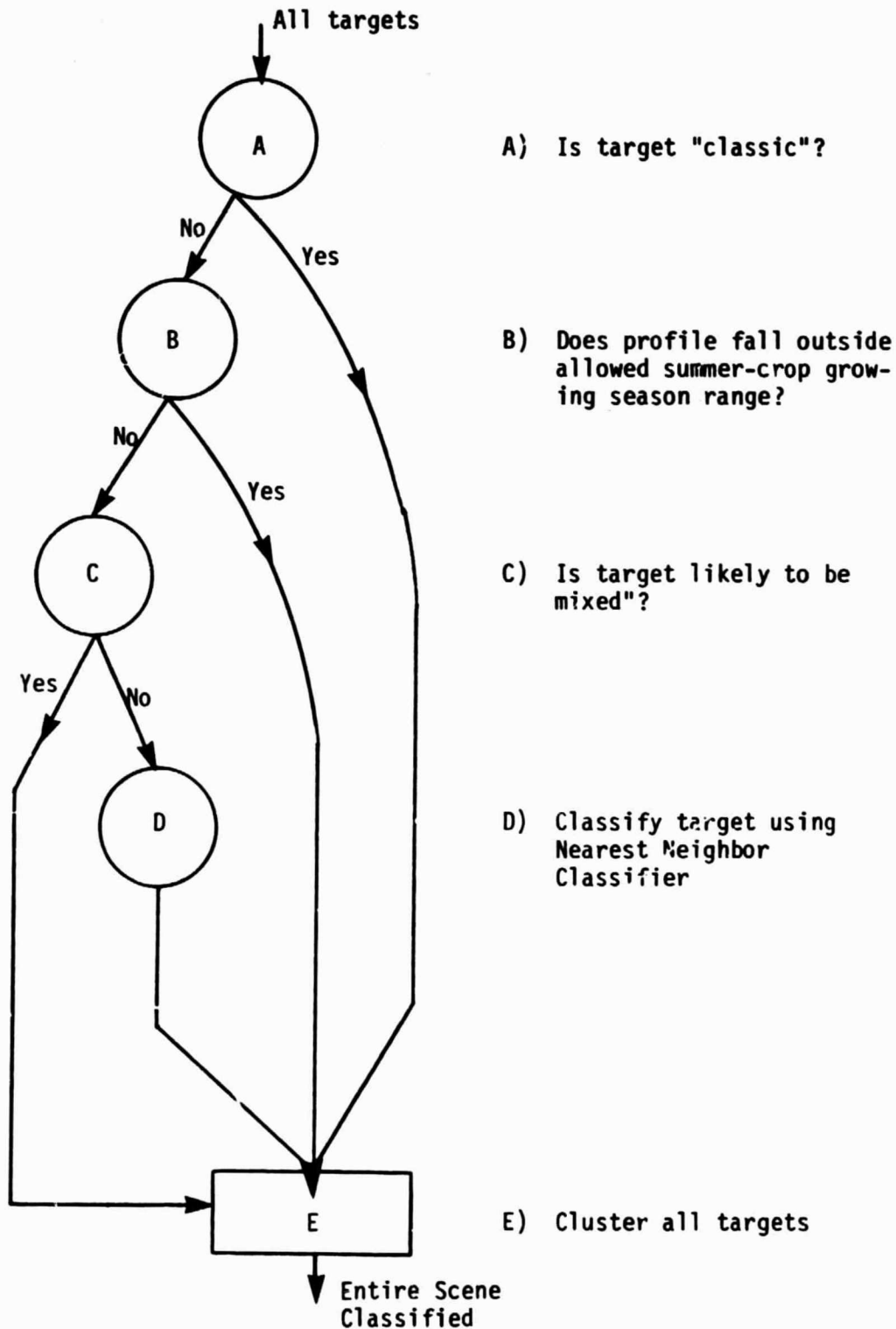


FIGURE 9. AUTOMATIC LABELING PROCEDURE FLOW

Selection of "Classic" Profiles. In analysis of the Greenness profiles of the crops of interest, particularly corn and soybean, it has been determined that there are several features which remain relatively invariant across fairly large regions, in this case, the Central U.S. Corn Belt (Iowa, Illinois and Indiana). Some of these features are:

- 1) Permanent vegetation and pasture is generally green throughout the growing season
- 2) Non-vegetated areas are not green during the growing season
- 3) Summer crop (corn and soybean) profiles generally have a single dominant vegetative phase
- 4) Tree profiles generally reach peak Greenness before corn
- 5) Corn profiles generally reach peak Greenness before soybean
- 6) Soybean profiles generally reach a higher peak Greenness than corn.

These features have been exploited to define a hierarchical decision logic which may be employed to capture and identify targets with "classic" profiles with high accuracy (see Figure 10). Since these are features which are relatively invariant across a large region, they cannot hope to capture all the variability present in such a region. The decision logic is chosen to be conservative in that, while it may have very high errors of omission (identifying typically 50% of the targets presented) the commission error rate on those targets is very low (<5%). The profiles identified as corn for a given scene are quite similar to each other, as are all the soybean profiles. Therefore, composite profiles are generated for each of these crops by averaging the profiles of all the targets with a given crop label, as seen in Figure 11.

The profiles identified as "non-summer" cover a much wider spectrum, ranging from never green (non-vegetated) to always green (permanent vegetation or pasture), and for this reason, no attempt is made to

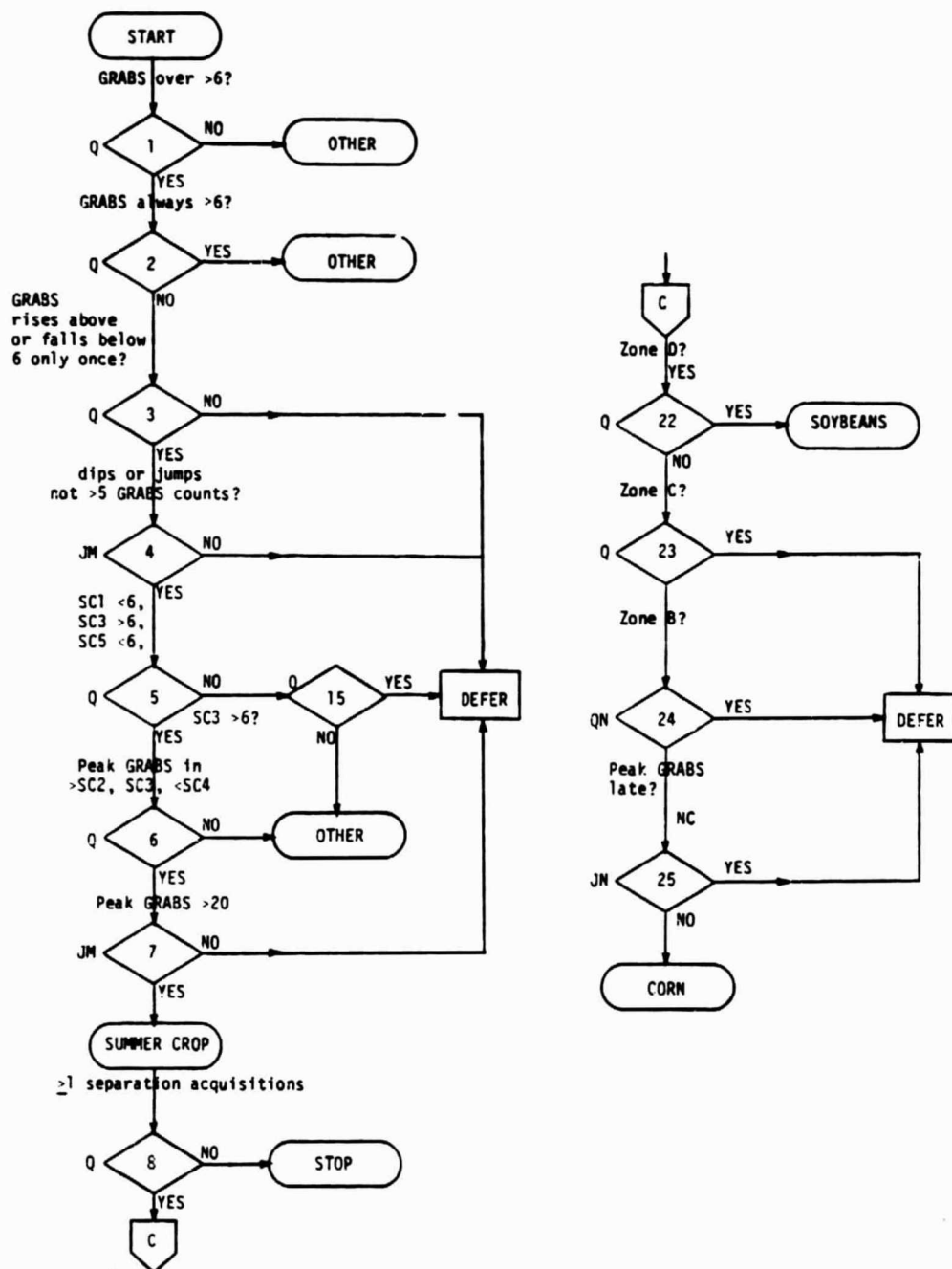


FIGURE 10. LOGIC USED TO IDENTIFY "CLASSIC" PROFILES

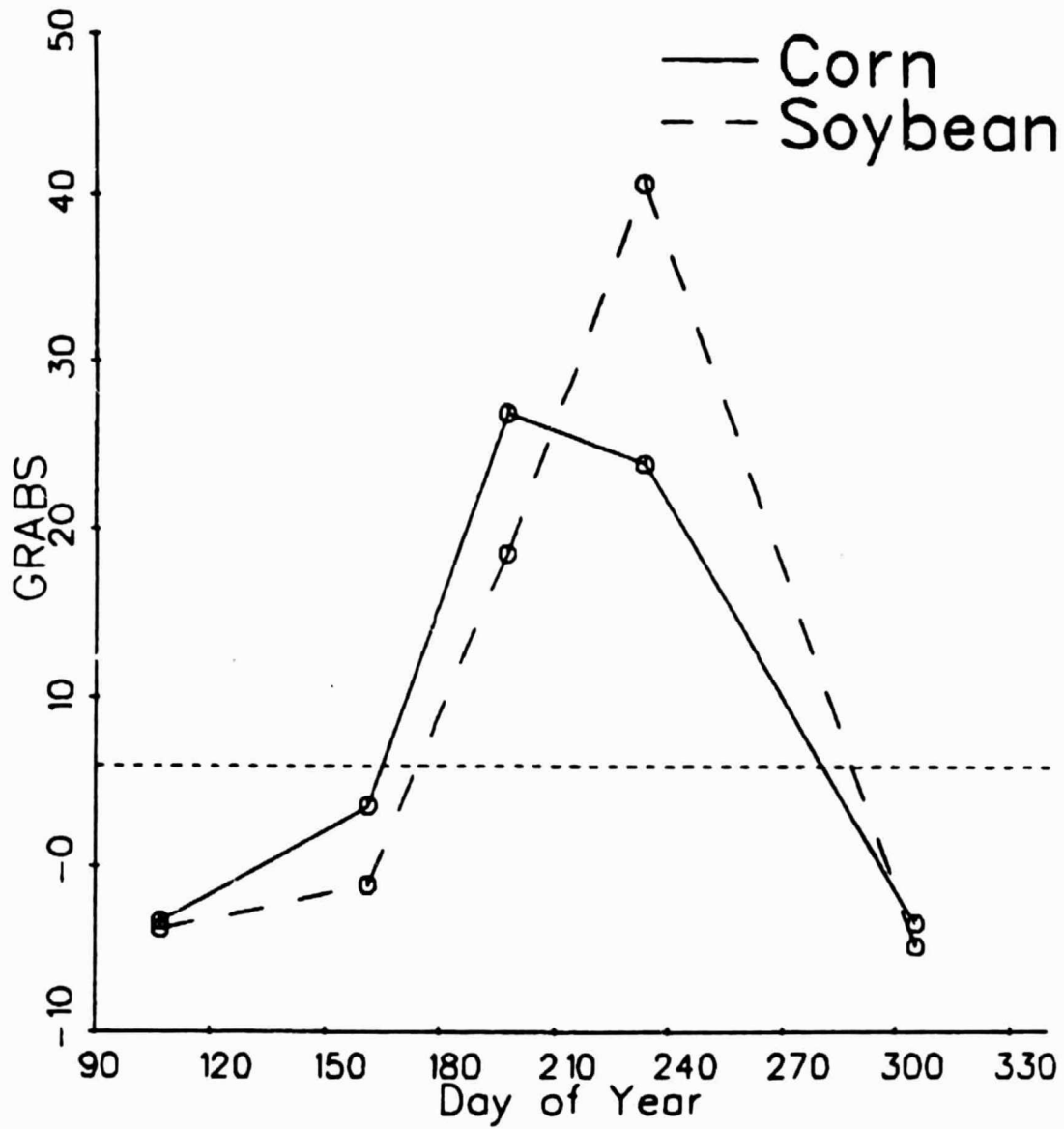


FIGURE 11. COMPOSITE CORN AND SOYBEAN "CLASSIC" PROFILES

derive a composite "non-summer" profile. Knowing that the duration of the summer crop growing season normally falls within a relatively small period, we can capture additional "non-summer" profiles which may have escaped detection by the hierarchical decision logic. To do this, the corn and soybean profiles are used to define a normal length for the summer crop growing season, and large deviations from this normal length are indicators of the profile being non-summer. This process identifies an additional 20-40% of the scene with a low (<5%) commission error rate.

At this point, 50-90% of the total area has been identified, with an accuracy of 90-95%. The remaining targets have "non-classic" profiles, and are the type of targets which are normally identified with the least accuracy by automatic procedures.

Classification of "Non-Classic" Profiles. These "non-classic" targets are typically composed of mixed signatures, or profiles of crops under varying types and amounts of stress. Previous work [11] showed that the overall shape of a corn or soybean profile may not change as much as the magnitude of the Greenness at any point on the profile. Therefore, classifying these profiles based on their overall shape was a logical approach to the problem of identifying the "non-classics". A Nearest Neighbor Classifier with Supremum Norm was selected as a technique which would best perform this shape matching, with the composite profiles derived from the "classic" targets being used as the reference or training set for the classifier. The use of these scene-specific composite profiles as the training set allows the classifier to operate with a training set which is adapted to the locally-specific conditions.

Targets with a high probability of being "mixed" (more than one crop) are held in reserve, with the remaining targets being classified with this classifier. Those targets which best fit the corn reference profile are labeled "corn", those which best fit the soybean profile are labeled "soybean", and those which poorly fit both the corn and

soybean reference profiles are labeled "non-summer" (see Figure 12). The classification process identifies an additional 10-50% of the scene, but with an accuracy of approximately 75%, somewhat lower than that achieved by the "classic" labeler - as is to be expected from the nature of the targets being identified. With 90-98% of the scene now identified, all that remain are the targets which have a higher probability of being mixed, and therefore are not expected to receive "pure" labels as have all targets up to this point.

All targets, "classic", "non-classic" and "probable mixed", are grouped using a spectral/temporal clustering algorithm [9]. The crop proportions of these clusters are computed from the labeled targets in each cluster, effectively labeling all the deferred, "probable mixed" targets, and completing the crop identification for the entire scene (see Figure 13).

Evaluation of Automatic Labeling Technique. To evaluate the technique described above, the labeler and classifier were implemented in an end-to-end segment area estimation procedure named C/S-1B. This procedure uses as labeling targets field-like structures called "blobs" which are defined by the BLOB algorithm, an algorithm which groups pixels which are spatially contiguous and spectrally similar over a set of acquisition dates [12]. The size of the scene processed was a 5 by 6 nautical mile segment, 117 scan lines of 196 pixels each. BLOB typically defined 700 to 1500 blobs for a segment, with approximately 70% of them (or 90% of the area) being "probable pure", the remaining 10% of the scene being "probable mixed". Approximately 40 spectral/temporal clusters of blobs were formed in each segment.

To perform the test, 53 segments of 1980 Iowa Landsat data were selected as being a data set independent of the 1978 and 1979 Iowa, Illinois and Indiana data utilized in the development of the procedure. Of these 53 segments, 22 had the wall-to-wall ground data necessary for evaluation of the procedure. This ground data was used to establish



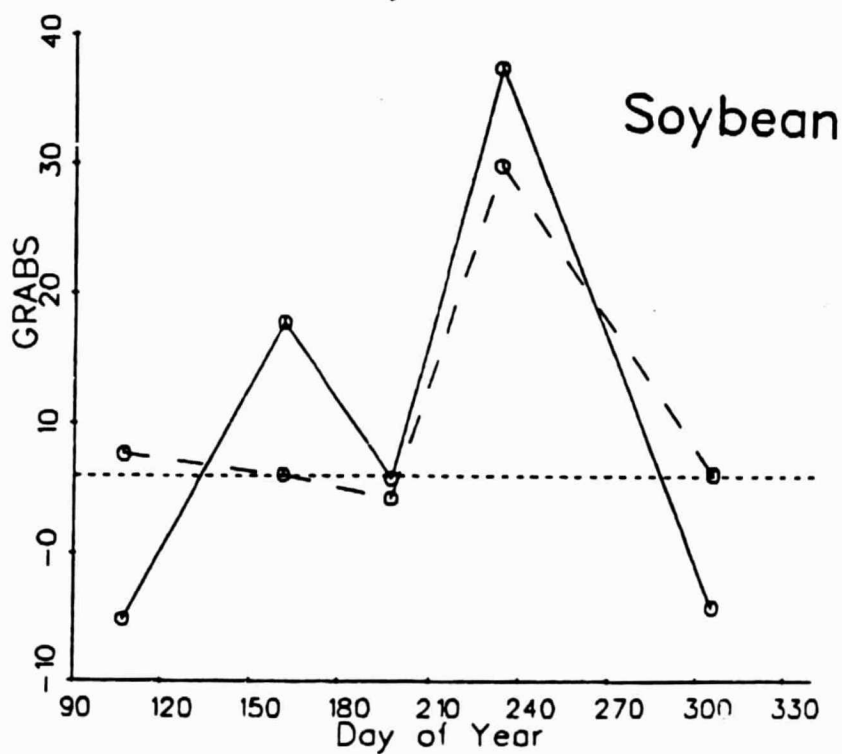
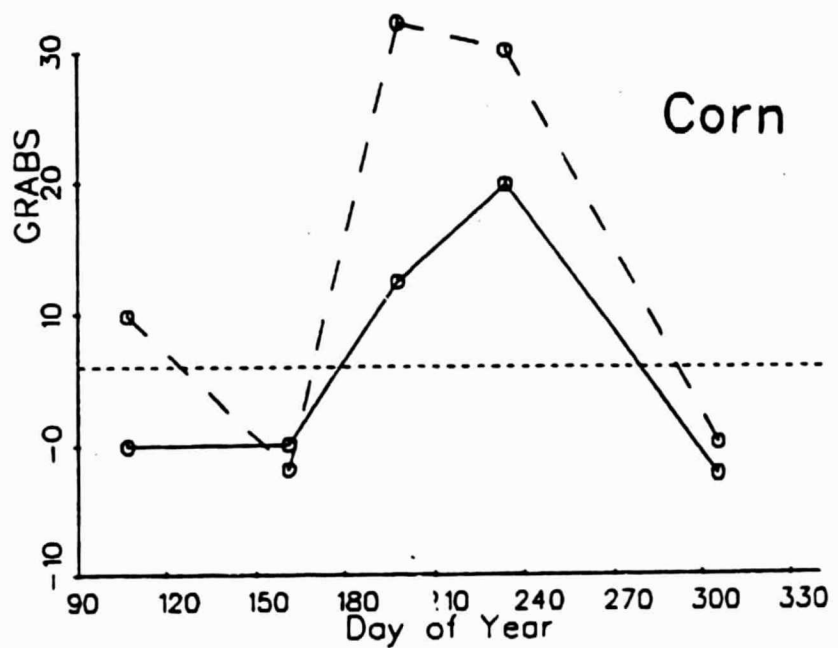


FIGURE 12. "NON-CLASSIC" PROFILES IDENTIFIED BY CLASSIFIER

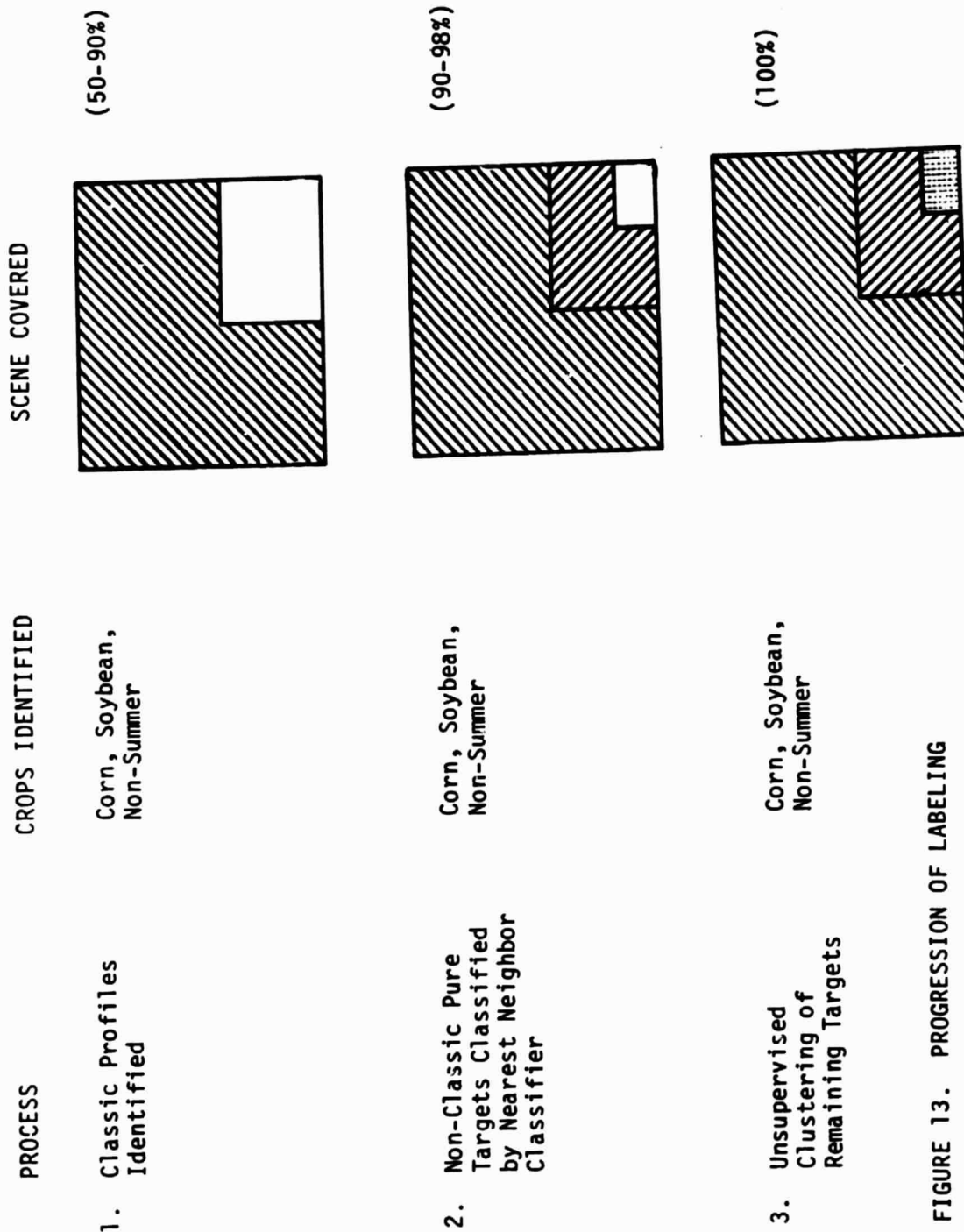


FIGURE 13. PROGRESSION OF LABELING

the "true" crop proportions for each segment, against which all proportion estimates were compared.

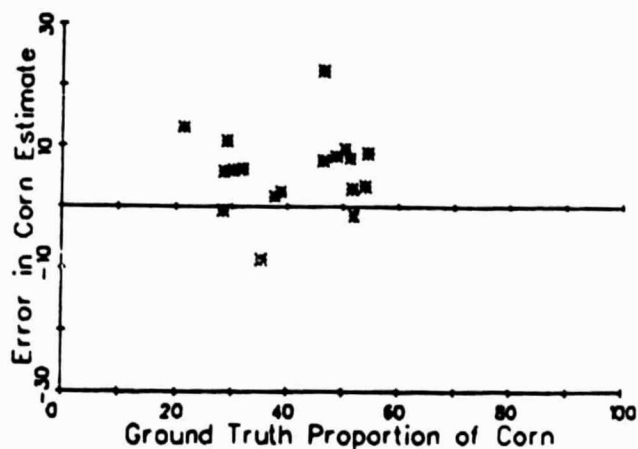
The acquisitions available for four of the 22 segments did not support the separation of corn and soybeans, having no acquisitions during the period when summer crops reached peak Greenness. For those four segments, only summer/non-summer identification was made. Figure 14 illustrates the proportion estimation accuracy of the procedure C/S-1B on the 22 segments (18 for corn and soybeans), Table 4 defines the statistics displayed in that figure.

The errors in estimating soybean proportions were consistently very low, being unbiased and with a variance uncharacteristically low for an automated labeling procedure. Although the variance in the corn and summer proportion estimates was higher than that for soybean (see Figure 15), these variances were still low for an automated procedure, comparing favorably with results from analyst-oriented procedures using similar data sets. The low variance observed with this labeling procedure appears to be due to the ability of the procedure to adapt to segment-specific conditions through the use of a generalized, conservative decision logic to select the training set for the classifier. A significant bias in favor of corn was observed, and with the soybean estimates being very good, this corn bias also appeared as a significant over-estimation of the proportion of summer crops in the segment. Earlier studies have indicated that the labeling targets formed by BLOB in the U.S. Corn Belt are not optimal, and in fact may contribute significantly to an over-estimate of corn [13].

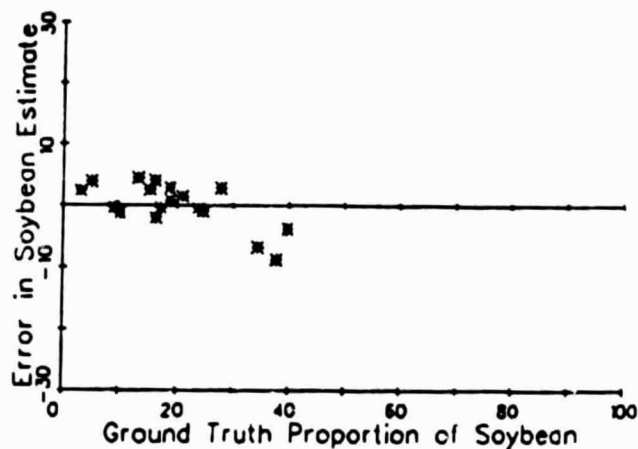
Conclusions. An automatic corn and soybean labeling procedure based on solid understanding of the crop phenology and the physical effects present when utilizing space remote sensing for crop inventory can provide accurate identification of crops without the requirement for ground observations. Familiarity with Greenness profiles for "normal" corn or soybean targets, and knowledge of how these profiles may vary from the "normal" profile for a crop led to the development of a procedure which



|           |       |
|-----------|-------|
| $\bar{e}$ | 5.89  |
| $S_e$     | 6.53  |
| R.M.E.    | 14.67 |
| M.A.E.    | 7.06  |
| $\bar{p}$ | 40.18 |
| n         | 18    |



|           |       |
|-----------|-------|
| $\bar{e}$ | -0.01 |
| $S_e$     | 3.61  |
| R.M.E.    | -0.05 |
| M.A.E.    | 2.76  |
| $\bar{p}$ | 18.24 |
| n         | 18    |



|           |       |
|-----------|-------|
| $\bar{e}$ | 6.03  |
| $S_e$     | 8.58  |
| R.M.E.    | 10.32 |
| M.A.E.    | 7.47  |
| $\bar{p}$ | 58.42 |
| n         | 22    |

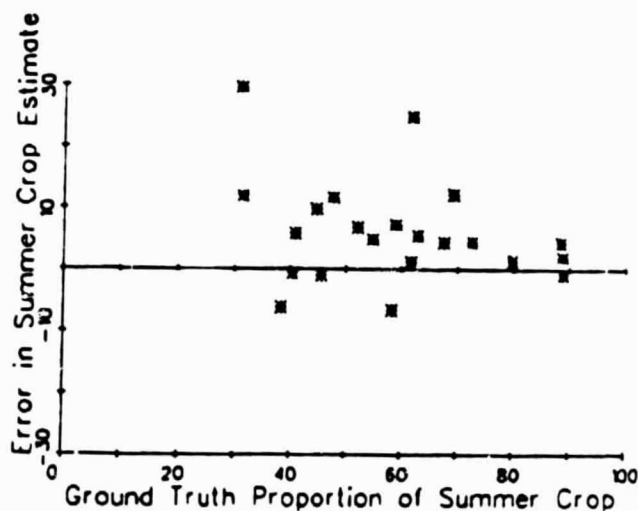


FIGURE 14. TEST RESULTS OF C/S-1B ON 1980 IOWA DATA

TABLE 4. STANDARD STATISTICAL MEASURES OF AREA PROPORTION ESTIMATION PERFORMANCE FOR n SEGMENT PROCESSINGS

- MEAN ERROR ( $\bar{e}$ ):  $\frac{\sum_{i=1}^n e_i}{n} = \hat{\bar{p}} - \bar{p}$
- STANDARD DEVIATION OF ERRORS ( $s_e$ ):  $[\frac{\sum_{i=1}^n (e_i - \bar{e})^2}{(n-1)}]^{1/2}$
- MEAN ABSOLUTE ERROR (M.A.E.):  $\frac{\sum_{i=1}^n |e_i|}{n}$
- RELATIVE MEAN ERROR (R.M.E.):  $\bar{e}/\bar{p}$

GROUND TRUTH PROPORTION FOR  $i^{th}$  SEGMENT:

$p_i$

ESTIMATED PROPORTION FOR  $i^{th}$  SEGMENT:

$\hat{p}_i$

ERROR FOR  $i^{th}$  SEGMENT:

$$e_i = \hat{p}_i - p_i$$

ABSOLUTE ERROR FOR  $i^{th}$  SEGMENT:

$|e_i|$

MEAN GROUND TRUTH PROPORTION:

$$\bar{p} = \frac{\sum_{i=1}^n p_i}{n}$$

MEAN ESTIMATED PROPORTION:

$$\hat{\bar{p}} = \frac{\sum_{i=1}^n \hat{p}_i}{n}$$

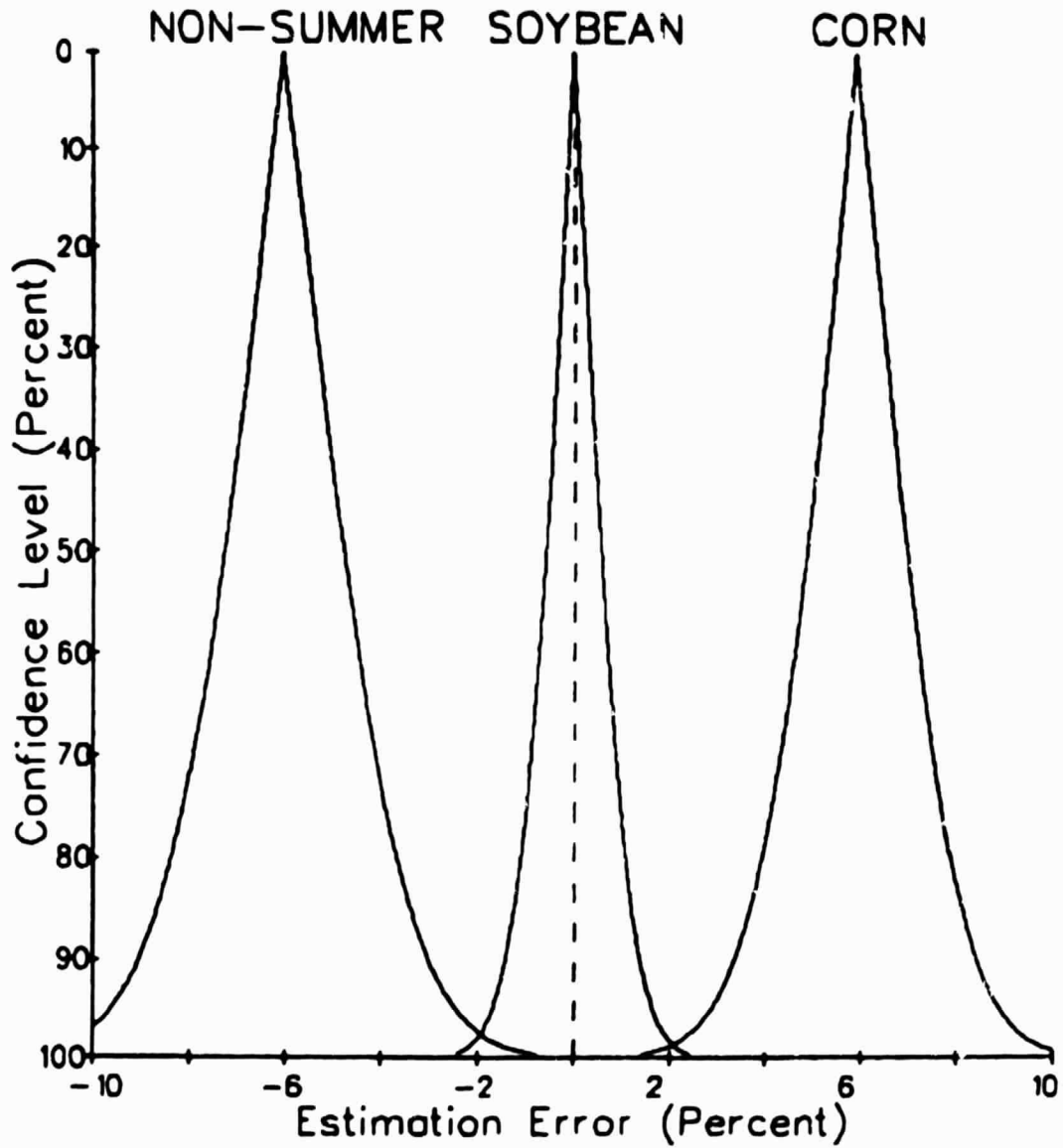


FIGURE 15. CONFIDENCE INTERVAL OF C/S-1B PROPORTION ESTIMATES

accurately identifies the "normal" profiles for corn and for soybeans for each segment, and a classifier which can accurately associate the deviant profiles with those "normals". This resulted in a procedure which successfully adapts itself to local conditions without the aid of a human analyst.

Evaluation of the labeling procedure in area estimation procedure C/S-1B indicated high accuracy in identification of soybeans, with less accurate estimates of corn proportions. This result may not accurately reflect the achievable accuracy of the labeling procedure in identifying corn targets as the targets provided by C/S-1B were known to cause a bias in favor of corn. Investigation of alternative methods of handling this mixed target problem will be the primary focus of this task for the remainder of the contract period.

#### 4.0

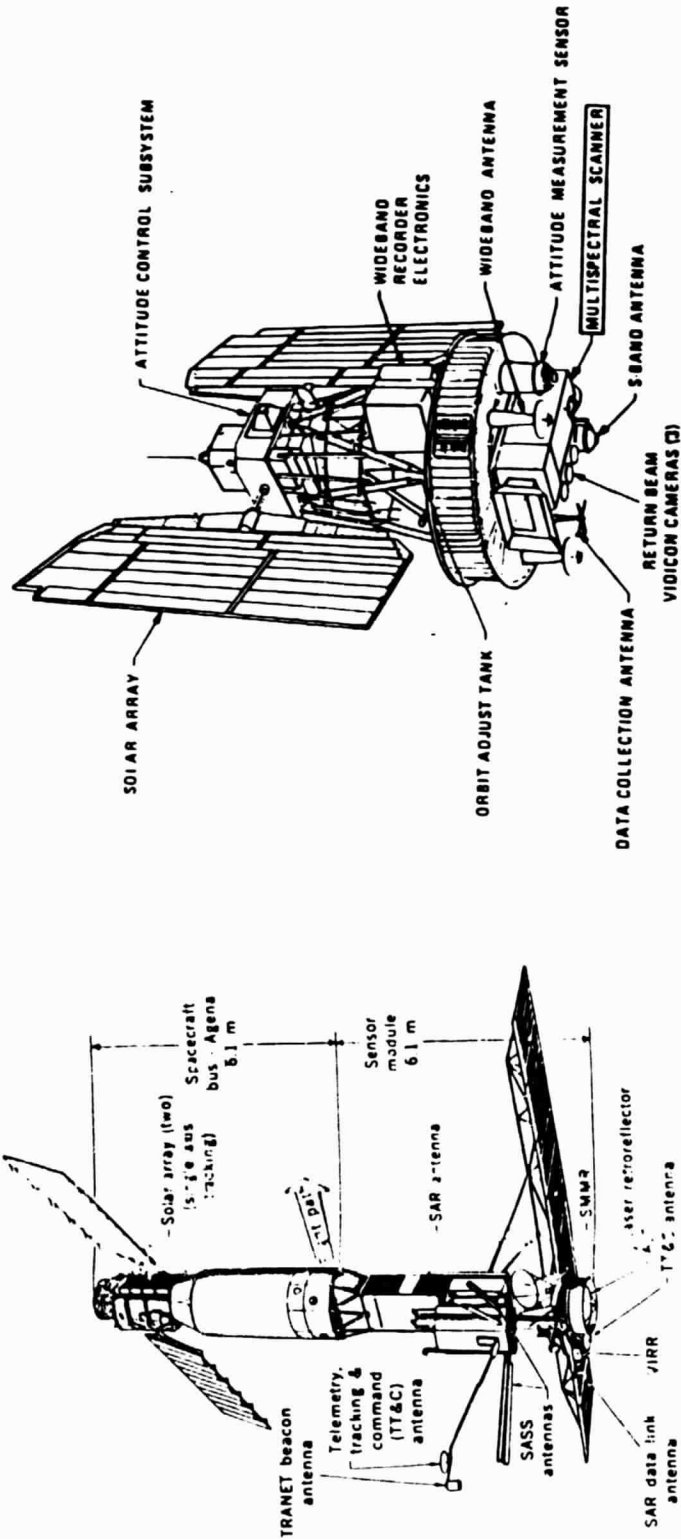
### ADVANCED SATELLITE AND SENSOR SYSTEM DEFINITION

Landsat MSS has been successfully applied to crop inventory applications as is evidenced by the LACIE wheat survey and by operational incorporation of Landsat data in USDA crop assessment surveys. However, both the spatial and spectral resolution of Landsat, and its dependence on an external source of illumination, limit the range and depth of application of this sensor. The goal of this task is to examine and exploit alternate sensor designs to determine additional information potential that can be derived from remote sensing.

SEASAT SAR with Landsat MSS. The initial objective of this investigation was to identify and illustrate the technical gains available to large area agricultural inventories through the augmentation of Landsat data by Synthetic Aperture Radar (SAR) data. Analyses were applied to both Landsat MSS and SEASAT SAR data collected during the 1978 growing season over an AgRISTARS test segment (844) in Jasper County, Indiana.

The SEASAT satellite was launched on 28 June 1978 and ceased operation prematurely on 10 October 1978 due to a power system failure. Illustrated in Figure 16, Seasat was the first earth satellite dedicated to a general study of the oceans with microwave sensors. Though intended for ocean imaging, the SAR was activated over land areas as well. This afforded the opportunity to analyze the potential of an active microwave scanning device for agricultural land use monitoring. Microwave returns are dependent on two key terrain features that could be unique with respect to ground cover - surface roughness and dielectric constant - to which Landsat MSS does not respond. In addition, using ERIM's hybrid image processing facility, SAR data from 25 July 1978 were converted to digital data at 25 m resolution offering the opportunity to examine benefits of finer spatial resolution.





THE LANDSAT SATELLITE

THE SEASAT SATELLITE

FIGURE 16. SATELLITE CONFIGURATIONS

Tone and Texture Processing. Figure 17 illustrates the extracted SEASAT SAR segment image registered to Landsat MSS segment 844. To minimize the coherent speckle, a non-linear isotropic filtering algorithm was employed using ERIM's Cytocomputer<sub>TM</sub>, a cellular automata based image processing capability. This algorithm avoids degrading edges, a problem that afflicts usual averaging procedures employed to remove speckle. Isotropic filtering consists of a sequence of 3x3 neighborhood dilations and erosions and requires no a priori knowledge of field boundaries. The result of this process is shown in Figure 18. The filtered image is then subtracted from the raw image and the resultant image, shown in Figure 19, called the texture image, represents the extracted coherent speckle.

Close examination of the texture image reveals noise patterns that can be associated with fields. Two texture measures were derived from this image. Contrast measures the amount of local variation in a sub-region and is defined as:

$$\text{con}(d,\theta) = \sum_{i=1}^{N_G} \sum_{j=1}^{N_G} (i-j)^2 P(i,j)$$

where

$d,\theta$  is the distance and angular displacement of a specific neighbor of pixel  $P(i,j)$

$N_G$  is the number of grey levels.

Entropy is a measure of local disorder and is large when a region is homogeneous. Entropy is defined as:

$$\text{ENT}(d,\theta) = \sum_{i=1}^{N_G} \sum_{j=1}^{N_G} P(i,j) \log P(i,j)$$

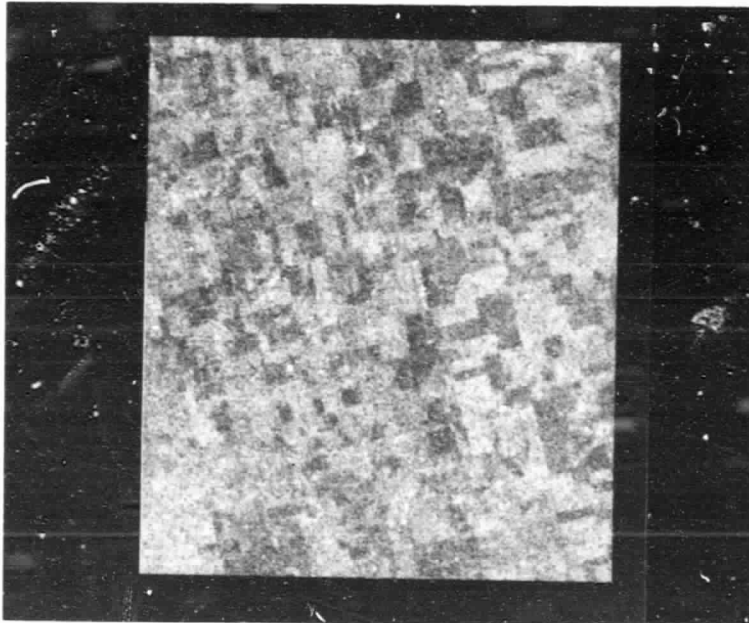


FIGURE 17. REGISTERED SEASAT DATA FROM SEGMENT 844

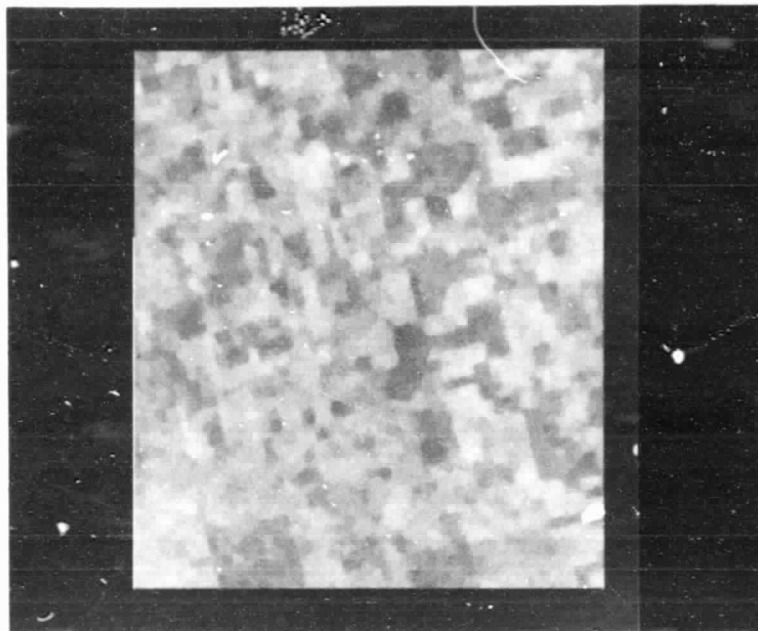


FIGURE 18. LOCAL TONE IMAGE

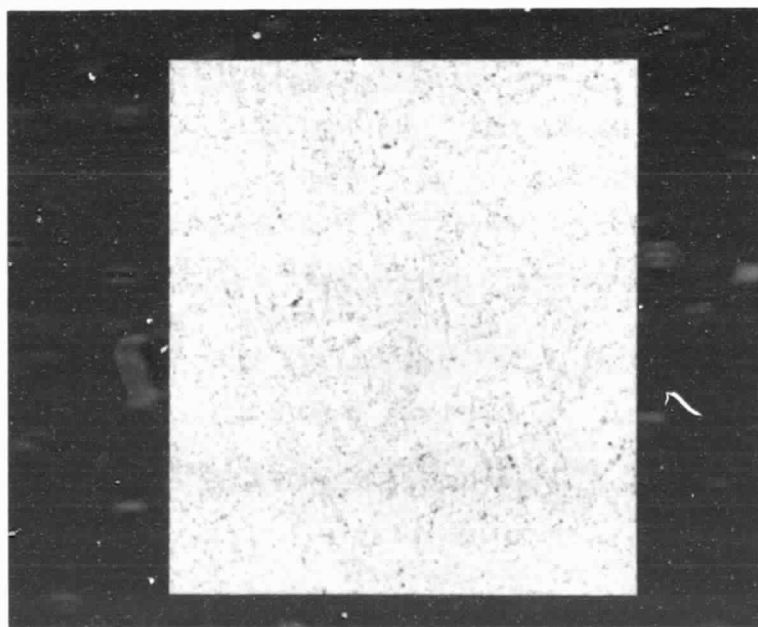


FIGURE 19. LOCAL TEXTURE IMAGE

As everyone knows, crops are generally planted in bare soil, emerge, develop, and grow to a maximum ground cover while producing seeds and fruits and are finally harvested. At each development stage, every plant type manifests its own particular textural pattern. In addition, most domestic crops are planted in rows. From ground level, row effects are obvious to human observers even when the row spacings are as small as 10-20 cm which is typical for wheat fields. Row effects are even more pronounced in crops like corn, soybean, or sorghum. These crops are usually planted in rows which are 60-90 cm apart.

Although the spatial resolution of SEASAT is substantially larger than these row spacings, certain, within-field textural variations are evident in the image. Potential sources of these variations are non-uniformities in the underlying soil characteristics, nutritional and moisture supplies, planting techniques, height and development stages across the fields. In relating the computed texture measurement values to specific crop types, the texture feature information was not regarded as a replacement but rather as an addition to the other features such as spectral, temporal and spatial information. In this case, it was found that low texture areas are mostly soybean fields, pasture areas and harvested wheat and sorghum fields while the high texture areas are from fields containing corn and other plants with considerable vertical development like trees and bushes. The combined use of an early Landsat acquisition to distinguish native vegetation from tilled vegetation along with the SEASAT SAR texture image enabled the separation of corn from soybeans approximately six weeks prior to spectral discrimination based on Landsat alone. In addition, due in part to improved ground resolution of SEASAT, field outlines for agricultural fields were improved over the use of the Landsat MSS alone.

Conclusions. This effort represents our first attempt at augmenting Landsat MSS data with SEASAT SAR imagery for digital crop classification. The results obtained provide a clear indication that, in spite of

coherent speckle, the SEASAT SAR data, with its high resolution, affords a more accurate representation of agricultural field boundaries when appropriate non-linear filtering techniques are employed.

SEASAT SAR data also provides additional spectral information in the sense that the backscattered signals tell us much about the surface roughness of different crop fields. The corn/soybean separability information contained in the SEASAT data from an acquisition date of July 25 corresponds closely to the information derived from Landsat data obtained on September 8. Thus, information from SEASAT could allow for an earlier estimate of the corn and soybean areas that can be achieved with Landsat alone.

The specific features of "tone" and "texture" derived from the SEASAT data produced somewhat different crop cover maps. However, the limited amount of data analyzed do not support a specific conclusion concerning the relative utility of these two features. The single acquisition of SEASAT data available did not seem to support crop identifiability beyond the separation of corn and soybeans. While it is possible that this represents a basic limitation on microwave agricultural remote sensing, drawing such a conclusion is certainly premature given the absence of multitemporal analyses which have been demonstrated to be so important in Landsat information extraction.

Finally, the analyses conducted provided some basis for anticipating that the joint use of Landsat and SEASAT could provide higher proportion estimation and mapping accuracy than could be achieved by either sensor alone.

## 5.0 SUMMARY

ERIM's support to the Inventory Technology Development Project of AgRISTARS is structured into three tasks:

- 1) Corn and Soybean Crop Spectral/Temporal Signature Characterization
- 2) Efficient Area Estimation Techniques Development
- 3) Advanced Satellite and Sensor System Definition

Pursuit of the objectives of these tasks during the first six-month reporting period has resulted in a successful period of progress.

A detailed statistical analysis of corn and soybean field measurement data base has provided important insight into those crops' signatures. Whereas a vegetative feature of soybeans was found to respond in a double-sigmoid manner, the corresponding corn spectral/temporal profile was found to 'plateau'. The use of this feature along with a maximum 'greenness' feature was found to completely separate the two crops. In addition variations from normal crop profiles as a function of environmental or cultural effects (e.g., moisture stress) were determined and crop growth stages were correlated to the spectral features.

Using standardized corn and soybean profiles, 'classic' features were determined and employed in an automatic area estimation technique. Results of an independent test on 1980 Iowa Landsat data indicated promising performance. Variance of the estimates were found to be very low, an unexpected result for an automatic technique, attributed in part to the procedure's attempt to adapt the 'classic' signature to scene specific characteristics. Though soybean estimates were unbiased, corn estimates revealed a significant bias that was due, at least in part, to the type of labeling target employed. Research in the remainder of

the contract period will emphasize the examination of this problem which is closely related to the mixed pixel problem.

Finally, SEASAT SAR data were used to augment Landsat MSS for crop inventory. This study found that SEASAT SAR data, with its high resolution, affords a more accurate representation of agricultural field boundaries that could be exploited using automatic edge detection algorithms. SEASAT SAR also provides additional spectral information in the sense that the back scattered signals relate to the surface roughness, i.e., canopy structure, of different crops. Two features called tone and texture, were extracted using a spatial data filtering approach based in cellular automata methods. It was found that, given comparable planting dates, corn and soybeans could be discriminated on the basis of surface texture differences earlier using SAR data in conjunction with Landsat than was possible using Landsat alone.



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APPENDIX A  
REPORTS AND PUBLICATIONS RELATED TO CONTRACT  
NAS9-16538 SEMI-ANNUAL REPORT

- Cicone, R.C. and M.D. Metzler. Comparison of Landsat MSS, Nimbus CZCS and NOAA 6/7 AVHRR Features for Land Use Analysis. Proceedings of the Symposium on Machine Processing of Remotely Sensed Data, Purdue University, West Lafayette, IND, 1982.
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